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(A) Header Information

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(B) Narrative Documentation

Long-term Research Objectives: My general long-term research objective is the development and application of adequate high-level mathematical techniques for the analysis of spatial data, in particular for remote-sensing data such as acoustic, seismic, bathymetric, and other geophysical data. My interest is in interdisciplinary work in mathematics, measuring techniques, acoustics, environmental information, geology and geophysics.

Scientific Objectives and Report Summary: The objective of my research under this grant is the development of an intelligent system for the automated classification of the seafloor using acoustic data. The work is a contribution to the Acoustical Reverberation Special Research Program (ARSRP). We have developed a method for surface classification, incorporating ideas from the theory of geostatistics (in short, the method has been called "Geostatistical classification method"). Under this project, we have finalized parameter selection and software development for the automated geostatistical seafloor classification method. Thereafter, we applied this method in a geomorphologic segmentation of the Western Flank of the Mid-Atlantic Ridge at 26°North, the area of geophysical survey under the ARSRP in 1992. High-resolution bathymetric data from the 1993 geophysical experiment were also analyzed and compared to the (low-resolution) HYDROSWEEP bathymetric data. Surface structures were found to be scale-dependent.

Background and Relationship to Other Research Projects: The problems investigated in this project have arisen in connection with the ARSRP data analysis, but are equally important for the analysis of acoustic and seismic data from deep and shallow ocean environments. Specific questions concern the statistical description of deafloor roughness and the relationship between surface (seafloor) parameteres and backscattering properties on the one side and geologic properties on the other side. The results are a contribution

to ocean acoustics, geophysical data analysis, quantitative morphology, and geologic segmentation of the seafloor.

Appraoch, Accomplishments, and Results:

Geostatistical Seafloor Classification

The objective of automated seafloor classification is to utilize statistical properties in quantitatively characterizing seafloor properties such as roughness and anisotropy. Such spatial characteristics are used to automatically distinguish geological provinces which facilitates a segmentation of the seafloor.

The geostatistical seafloor classification method has been developed in relationship to the analysis of data from the western flank of the Mid-Atlantic Ridge at 26°N. We have analyzed (low-resolution) HYDROSWEEP bathymetric data from the 1992 geophysical experiment in which I participated (cf. Herzfeld 1993) and high-resolution (5 m) data from the 1993 geophysical experiment collected by K. Stewart with the DSL instrument developed at Woods Hole Oceanographic institution (cf. paragraph on "Relationship to other projects").

The geostatistical seafloor classification method is based on calculation of directional variograms as spatial structure functions. Parameters determined from filtered variogram functions are used to compose feature vectors, which have been shown to characterize morphologic prototypes and surface roughness types (Herzfeld 1993a) and therefore facilitate a classification. The variogram is the lag-dependent spatial structure function of geostatistics, the theory of regionalized variables (Journel and Huijbregts 1989). The variograms are filtered, parameters extracted, and a feature vector is composed of the parameters (Herzfeld and Higginson 1996). Discriminants include spacing and strike of abyssal hill terrain, smoothness due to sediment cover, and parameters related to complexity and morphological significance of abyssal hills and their slopes (cf. Figures 1 and 2). Figure 1 shows the MINDIST parameter which characterizes the typical length of features in east-west direction (that is, roughly in the across-strike direction in the survey area on the Western Flank of the Mid-Atlantic Ridge). Figure 2 depicts the parameter P1 indicative of significance of abyssal hill terrain (slope parameter) for the 150km by 100km area shown in Figure 1. More parameters and combinations of parameters are described and applied in Herzfeld and Higginson (1996).

Complications of the automatization concern robustness of parameter estimation, optimal window size, and subselection of data. By moving a classification operation through the study area and color-coding property classes, seafloor classification maps are obtained. The concepts of characteristic parameters, feature vectors, and discrimination criteria are introduced in Herzfeld and Higginson (1996). The updated version of the program contains an option for automatic selection of the locally dominant direction in areas with anisotropies (typical for the ridge flank). This search succeeds in identifying structures inobvious to the eye.

Seafloor Segmentation

The geostatistical classification method has been applied in segmentation of the entire 600 km by 250 km area of the 1992 geophysical survey. The segmentation is based on HYDROSWEEP data. It should be mentioned that the method is robust enough to evaluate data with relatively high error levels and with gaps in the data coverage (both of which occured in the 1992 HYDROSWEEP data).

Maps of parameters MINDIST, POND, and significance of abyssal hill terrain (slope parameter P1 and relative-size parameter P2) and of parameter combinations have been produced. The map of parameter combination MINDIST and POND is given in Figure 3. The POND parameter shows flat areas, typically

Figure 1.
Parameter MINDIST

Figure 2.
Parameter P1

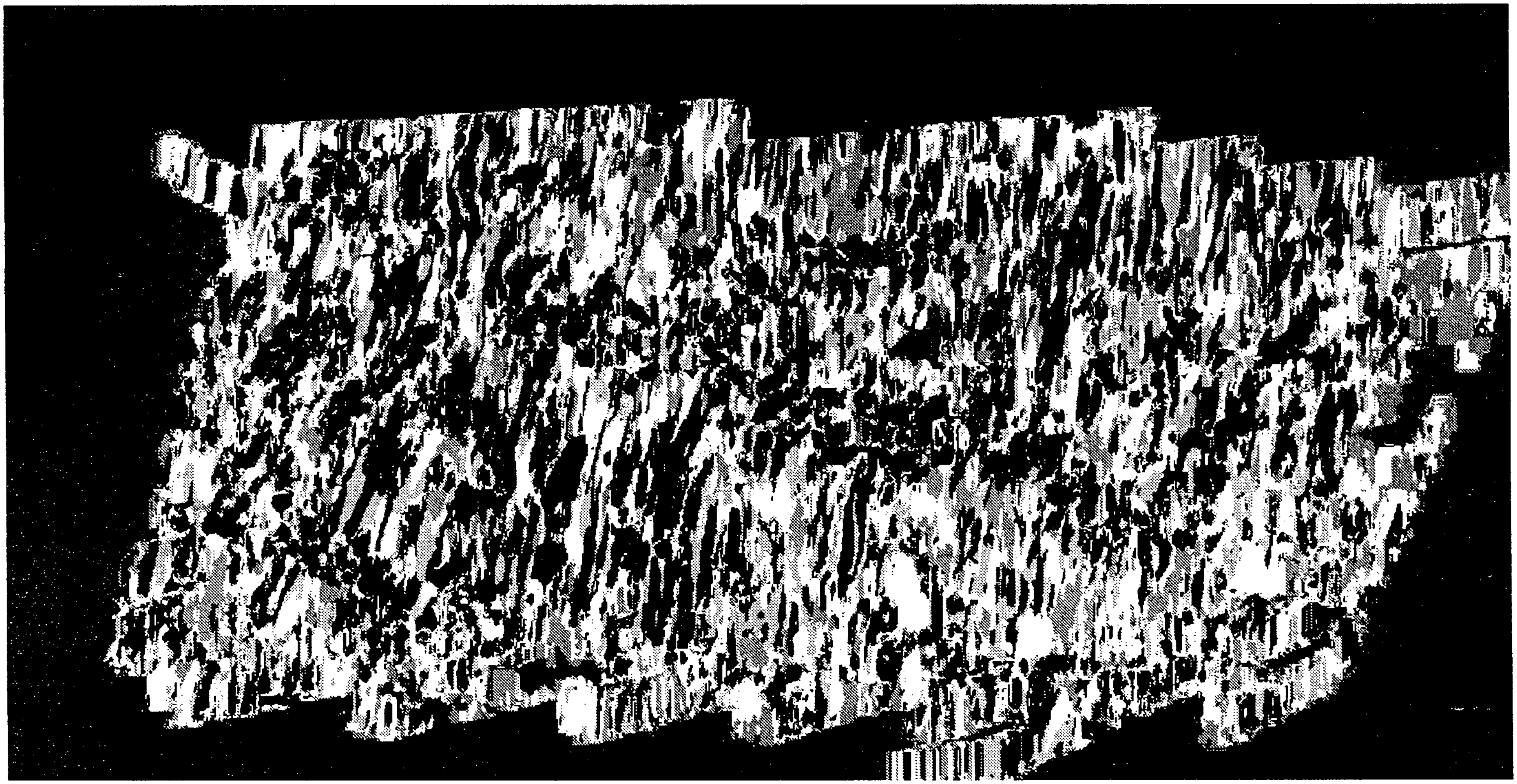

Figure 3.
Combination of PODD and MINDIST parameters.
Basis for segmentation of 600×250 km off-axis area

sediment ponds (notice it depicts the interior of larger ponds due to the moving window operation). Areas without significant features are marked in black (no min-max sequence found). Connected black areas trending from lower right to upper left in the map in Figure 3 delineate the location of discontinuities, which separate three ridge flank segments of different characteristics. The central segment has with distance from the ridge crest (spreading center) gradually increasing sizes of characteristic spacing of abyssal hill terrain, this is indicative of relatively undisturbed Atlantic crust. The northern segment appears to be overprinted by a process other than seafloor spreading, which is obvious from the less parallel and less connected smalles color patches. A third segment can be distinguished in the lower left corner of the map. Some of this interpretation is inferred from maps of other parameters and multidirectional analysis maps not shown in this brief report. The results will appear in Herzfeld (1997).

Results of our work have been presented at the 1994 AGU Fall meeting, at the 1995 meeting of the International Union for Geodesy and Geophysics in Boulder, and at the 1996 meeting of the European Geophysical Society (cf. Abstracts).

Scale-dependent Properties ("Fractal analysis")

Theoretical work on fractals and scaling properties and analysis of seafloor profiles from various parts of the seafloor indicated that the ocean floor does not follow a self-similar or self-affine model (Herzfeld 1993b, Herzfeld et al. 1993a, Herzfeld et al. 1995). Analysis of DSL120 high-resolution data with the classification method revealed once more that the characteristics of the seafloor at 5 m resolution are different from those at about 125 to 200 m resolution. If the seafloor were self-similar, maps of parameter P2 would simply show the same pattern and colors at both resolutions, which is not the case. Rather than just show that features are different, the classification maps yield information on the scale-dependent morphologic characteristics.

Relationship to Other Projects:

The project is part of the ARSRP data analysis. Data have been collected during the cruises EW9208 in 1992 (Chief Scientists B. Tucholke and M. Kleinrock) and during the geophysical cruise in 1993 (Chief Scientists K. Stewart and B. Tucholke). I participated in the 1992 cruise with the Maurice Ewing. Development of our geostatistical classification system benefited from the development of graphics programs by M. Marra and K. Stewart (WHOI). Ken Stewart's group has been working on classification, but on a different scale and using a different approach. We have given a few joint presentations at ARSRP meetings and at the IUGG meeting (cf. Abstract). Results of the geostatistical surface classification can be made available to the research community for testing of acoustic models and to aid in geologic investigations.

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(2) HERZFELD, U.C. and C.A. HIGGINSON, Automated geostatistical seafloor classification — principles, parameters, feature vectors, and discrimination criteria, Computers & Geosciences vol. 22, no. 1 (1996), p. 35-52

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Statistical Information:

Publication list: enclosed

Graduate Students: C. A. Higginson

Service on Committees:

Associate Editor: Computers & Geosciences, International Association for Mathematical Geology (since 1995, Assistant Editor 1987–1994)

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Assistant Editor: Mathematical Geology, International Association for Mathematical Geology (since 1994)

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RESUME

Born: November 24, 1960, Lieser, Kreis Bernkastel-Wittlich, Germany

Education

1978-1983	Scholarship, German National Scholarship Foundation, Bonn, Germany
1980-1981	Scholarship for Studies Abroad, German National Scholarship Foundation, Bonn, at the University of Warwick, Coventry, Great Britain
Dec. 1983	State Examination (Master's Degree), Mathematics, Evangelical Theology, Johannes Gutenberg-Universität Mainz, Germany (summa cum laude)
1982-1986	Study of geology, oceanography, geophysics, physical geography, glaciology
1984-1986	Doctoral Fellowship, German National Scholarship Foundation, Bonn
June 1986	Doctoral Degree (Dr. rer. nat.), Mathematics secondary subjects applied mathematics and geosciences, Johannes Gutenberg-Universität Mainz
1986	Diploma of Postgraduate Studies, Mathematical Geology, Free University of Berlin, Germany

Positions and Awards

1980-1986	Teaching Assistant in mathematics, Universities of Mainz and Warwick, Coventry, Great Britain
Oct.-Nov.1984	Assistant Research Scientist during Expedition ANTARKTIS III/1, RV POLARSTERN, Alfred Wegener Insitute for Polar and Marine Research, Bremerhaven, Germany
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1987-1988	Postdoctoral Research Fellow (DFG) and Lecturer, Mathematical Geology, Free University of Berlin, Germany
Dec.1987-Apr.1988	Research Scientist, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Expedition ANTARKTIS VI/3
Oct.1988-Sept.1992	Feodor Lynen Research Fellow, Alexander von Humboldt Foundation, Bonn, Germany, at Scripps Institution of Oceanography, University of California at San Diego, USA
Jun.1991-Nov.1993	Assistant Research Geomathematician (Project Scientist) at Scripps Institution of Oceanography, University of California San Diego
1992	President's Prize of the International Association for Mathematical Geology
Aug.1993-pesent	Research Associate, Institute of Arctic and Alpine Research, University of Colorado, Boulder

Ute Christina Herzfeld 19 March 1997

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